Climate Change Trends, Vulnerabilities, and Paleontology,
John Day Fossil Beds National Monument, Oregon

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July 21, 2016

Climate Trends for the Area within Park Boundaries

- **Historical temperature** Average annual temperature in the park increased at the statistically significant rate of +1.1 ± 0.4°C per century (2 ± 0.7°F. per century) in the period 1950-2013 (Table 1, Figure 1). The greatest rate of increase occurred in spring.
- **Historical Precipitation** Total annual precipitation decreased slightly in the period 1950-2013, but the rate was not statistically significant (Table 1, Figure 2).
- **Spatial patterns** Historical temperature increases have been greater in the Clarno Unit (Figure 3). Historical precipitation changes were low across the park (Figure 4).
- **Future projections** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming and changes in precipitation (Table 1, Figure 5).
- **Projected precipitation** For projected average annual precipitation, most climate models project an increase, but some individual models project decreases.
- **Aridity** Even if precipitation increases, temperature increases may overcome any cooling effects, leading to increased evapotranspiration and overall aridity.
- **Extreme heat** Projections under the highest emissions scenario project an increase of 3 to 6 more days per year with a maximum temperature >35°C (95°F.) (Kunkel et al. 2013).
- **Extreme storms** Projections under the highest emissions scenario project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-6 years (Walsh et al. 2014).

Paleontology Research in the Park Relevant to Human Climate Change

- **Greenhouse Effect** Analyses of soil deposits up to 35 million years old (paleosols) from sites across the western U.S., including sites in the park, found that global temperature was related to atmospheric CO_2 concentrations (Retallack 2007). In this way, paleontological data from the park has contributed to scientific documentation of the Greenhouse Effect, which governs human climate change today.
- **Mammal diversity** Analyses of mammal fossils up to 65 million years old (Cenozoic Era) from across North America, including sites in the park, indicate that mammal diversity tends to increase in climatically stable periods, then decline abruptly when global temperatures increase substantially (Figueirido et al. 2012). In this way, paleontological data from the park has contributed to scientific understanding of the past five mass extinction events that foreshadow aspects of the current sixth mass extinction of plants and animals (Lawton and May 1995).
- **Tree shifts** Analysis of tropical cedar (Genus *Cedrela*) fossils up to 31 million years old from across North and South America, including sites in the park, and genetic analyses of current-day plants found a north-to-south biome shift in paleoecological time driven by temperature and precipitation changes and diversification of species climate requirements (niches) over time (Koecke et al. 2013).
- **Species adaptations** Analyses of ancient soil deposits fossils from 23 to 56 million years ago from the Clarno and John Day units of the park indicated changes in the ecological preferences of plants, snails, and mammals (Retallack 2004). Extinct relatives of flowering plants (Genera *Meliosma* and *Oreomunnea*) and snails showed adaptations to waterlogged, nutrient-deficient, and toxic (metallic) soils.
- **Degradation of fossils** Fossils in the park, especially those exposed to the open air, are vulnerable to degradation from natural weathering in sunlight, wind, and rain, and from wind and water erosion (Santucci et al. 2009). Any increase of extreme storms under climate change (Walsh et al. 2014) could increase erosion and the vulnerability of fossils on riverbanks and in riparian areas. Waterlogged soil increases vulnerability of paleosol-derived plant fossils, while arid and high-salinity soil conditions increase the vulnerability of paleosol-derived fauna fossils (Retallack 2004). Any degradation of fossils under climate change could affect the types, numbers, and locations of fossils found in an area and affect interpretation of the paleontological record of the region (Behrensmeyer et al. 2000).

Historical Impacts in the Region Attributed to Human Climate Change

- **Wildfire** Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor determining how much land burned, even during periods of active fire suppression (Littell et al. 2009).
- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including counts in central Oregon, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human climate change (La Sorte and Thompson 2007). Further analyses demonstrate poleward shifts in winter distributions of six raptor species listed by the NPS Inventory and Monitoring Program as breeding in the park (American Kestrel (*Falco sparverius*), Golden Eagle (*Aquila chrysaetos*), Northern Harrier (*Circus cyaneus*), Prairie Falcon (*Falco mexicanus*), and Red-tailed Hawk (*Buteo jamaicensis*)) or observed in the park (Rough-legged Hawk (*Buteo lagopus*)) (Paprocki et al. 2014).

Future Vulnerabilities in the Region

- **Wildfire and invasive plant species** Under high emissions, fire frequencies could increase in the region up to 25% by 2100 (Moritz et al. 2012) and the region of the park would continue to provide suitable habitat for invasive cheat grass (*Bromus tectorum*) and yellow starthistle (*Centaurea solstitialis*) (Bradley et al. 2009).

  Research from 1998 to 2014 in the Sheep Rock unit of the park on plots burned and unburned with prescribed fire found that the surface area of invasive cheatgrass increased by a third in Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) areas and tripled in western juniper (*Juniperus occidentalis*) areas fire years after burning (Reed-Dustin et al. 2016). The surface area of native bluebunch wheatgrass (*Pseudoroegneria spicata*) decreased by half in juniper areas, returning to previous levels after two years on cooler north-facing slopes and five years on hotter south-facing slopes (Reed-Dustin et al. 2016). Field surveys in the park of native bluebunch wheatgrass and Sandberg bluegrass (*Poa secunda*) and modeling of habitat indicated that they were more abundant on cooler north-facing slopes, outside of recently burned and with lower invasion of exotic grasses (Rodhouse et al. 2014).

  Analysis of fires in the Great Basin, including parts of Oregon, Nevada, California, Idaho, and Utah, indicated that, from 1980 to 2009, 13% of the surface area of invasive cheatgrass-dominated lands burned, double the fraction of other vegetation types, and that cheatgrass fires tended to increase after wet years (Balch et al. 2013).

In the Eastern Oregon Agricultural Research Station south of the park, experimental research on three invasive annual grass species found in the park (cheatgrass [*Bromus tectorum*], medusahead [*Taeniatherum caput-medusae*], and ventenata [*Ventenata dubia*]), indicated that ventenata responds least to changes in precipitation and that medusahead root growth increased in response to watering that simulated extreme precipitation events followed by longer dry periods (Bansal et al. 2014). Medusahead in the western U.S. reduces biodiversity, wildlife habitat, and forage production, alters ecosystem function, and often increases fire frequency and restoration costs (Nafus and Davies 2014).

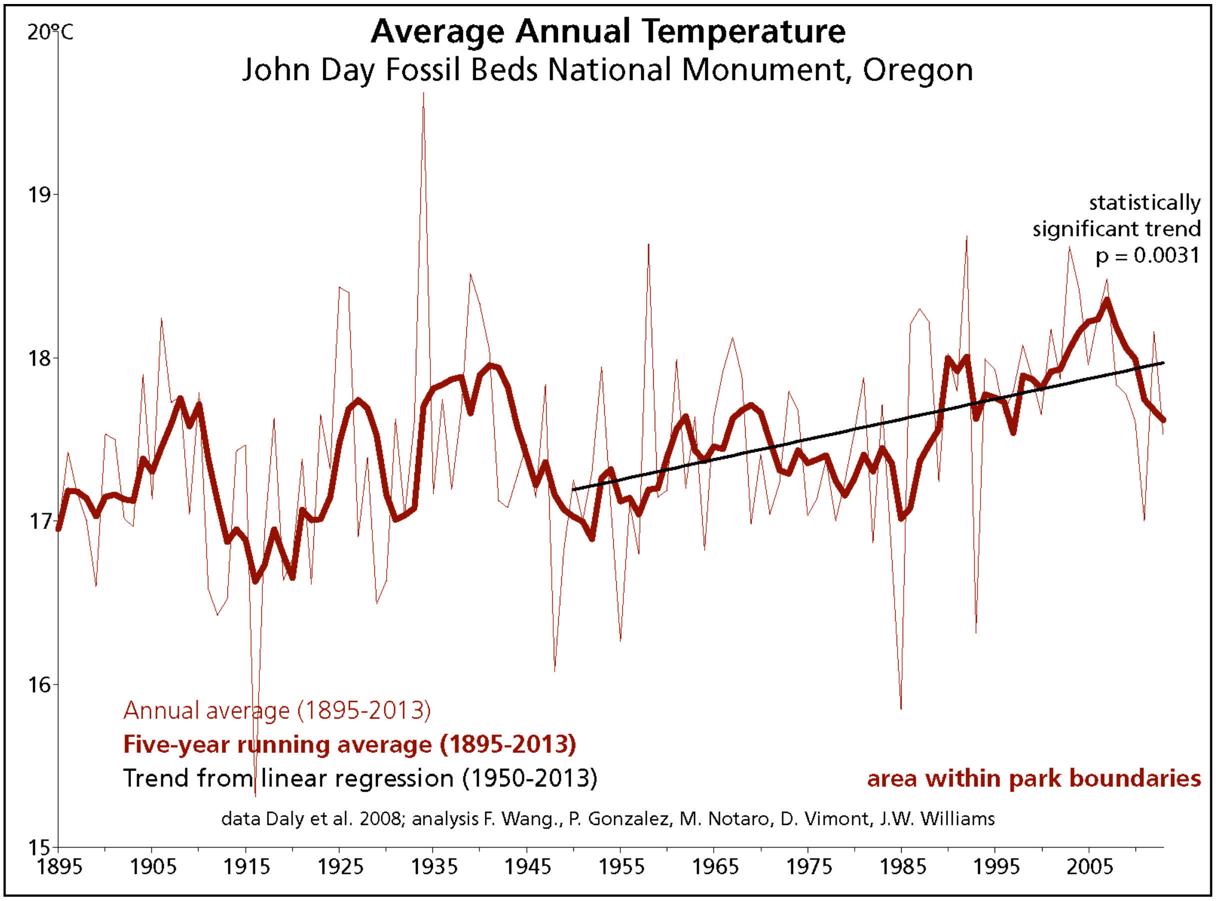
- **River flow** Under a medium emissions scenario, reduced snowfall and increased temperature could reduce June flow of the John Day River by up to 10% by mid-century and shift peak flow earlier into the winter (Mote et al. 2014).
- **Trout (research in the John Day River Basin)** Water temperature in the North Fork of the John Day River affects seasonal distribution of sub-yearling Chinook salmon and Smallmouth bass (*Micropterus dolomieu*), increasing vulnerability of salmon to predation by bass under climate change (Lawrence et al. 2012). Vulnerability may be higher in the relatively warmer, less steep Middle Fork (Lawrence et al. 2014). Offspring survival of Steelhead trout (*Oncorhynchus mykiss*) in the river basin may be most closely related to growing-season-degree-days, suggesting vulnerability to higher stream temperatures under climate change (Falke et al. 2013). Bull trout (*Salvelinus confluentus*) are vulnerable to extirpation throughout most of the basin due to very cool water temperature requirements (Rieman et al. 2007). Under a high emissions scenario, habitat in the basin may decrease substantially for Chinook salmon (*Oncorhynchus tshawytscha*) (69-95%), Rainbow trout (*O. mykiss*) (51-87%), and Bull trout (*Salvelinus confluentus*) (86-100%) (Ruesch et al. 2012).
- **Trout (research in the region)** Across the Columbia River Basin, including the John Day River, populations of Bull trout located in the most upstream headwater areas show the greatest genetic diversity, increasing with increasing habitat patch size and decreasing with maximum summer temperature and frequency of winter flooding, suggesting vulnerability of genetic diversity to projected climate change (Kovach et al. 2015). In Oregon, increasing summer stream temperatures and reduced snowpack could alter flow regimes and bury gravel essential for spawning trout (Lawler et al. 2010). Elsewhere in the Pacific Northwest, non-native brown trout (*Salmo trutta*) increase the vulnerability of native cutthroat trout (*Oncorhynchus clarkii*) to warmer waters (Wenger et al. 2011).

- **Trout (habitat management options)** Because elevated water temperatures are linked to riparian vegetation loss, reducing cattle grazing within riparian areas could foster recovery of woody vegetation and provide shade relief for trout (Ruesch et al. 2012). Without riparian restoration, rearing habitat for sub-yearling Chinook salmon could nearly disappear by 2080 AD under a medium emissions scenario (Lawrence et al. 2014).
- **Bats (aridity)** Increasing aridity can reduce bat reproduction (Adams and Hayes 2008). Bats may be disproportionately affected by increased aridity relative to other mammals because small body size and a large surface area to volume ratio predisposes them to dehydration through evaporative loss (Adams 2010).
- **Bats (White Nose Syndrome)** White-nose syndrome (*Pseudogymnoascus destructans*) occurrence is associated with precipitation frequency (30% of days with any precipitation), annual temperature (38-40°C), mean temperature of the wettest quarter (2-17°C), and precipitation during the wettest month (<100 mm) (Flory et al. 2012). In North America, white-nose syndrome has been detected in big brown bats (*Eptesicus fuscus*) and little brown bats (*Myotis lucifugus*), two species native to the park. Under historical and projected climate, some conditions are suitable in the park for White-nose syndrome. Because infected bats suffer from dehydration during hibernation (Willis et al. 2011), mortality is associated with colder conditions when water sources are frozen and with drier conditions when less water is available (Flory et al. 2012). Bats may survive by arousing from hibernation to hydrate and warm to euthermic temperatures outside hibernacula (Flory et al. 2012).

Table 1. Historical rates of change and projected future changes per century in annual average temperature and annual total precipitation for the park as a whole (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2013. The U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. The table gives central values with standard errors (historical) and standard deviations (projected).

	1950-2013	**2000-2100**
Historical		
temperature	+1.1 ± 0.4°C per century (2 ± 0.7°F. per century)	
precipitation	+2 ± 13% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		+1.7 ± 0.8°C per century (+3.1 ± 1.4°F.)
precipitation		+8 ± 7% per century
Low emissions (IPCC RCP4.5)		
temperature		+2.7 ± 0.9°C per century (+4.9 ± 1.6°F.)
precipitation		+7 ± 8% per century
High emissions (IPCC RCP6.0)		
temperature		+3.1 ± 0.9°C per century (+5.6 ± 1.6°F.)
precipitation		+9 ± 8% per century
Highest emissions (IPCC RCP8.5)		
temperature		+4.7 ± 1.1°C per century (+8.5 ± 2°F.)
precipitation		+11 ± 10% per century

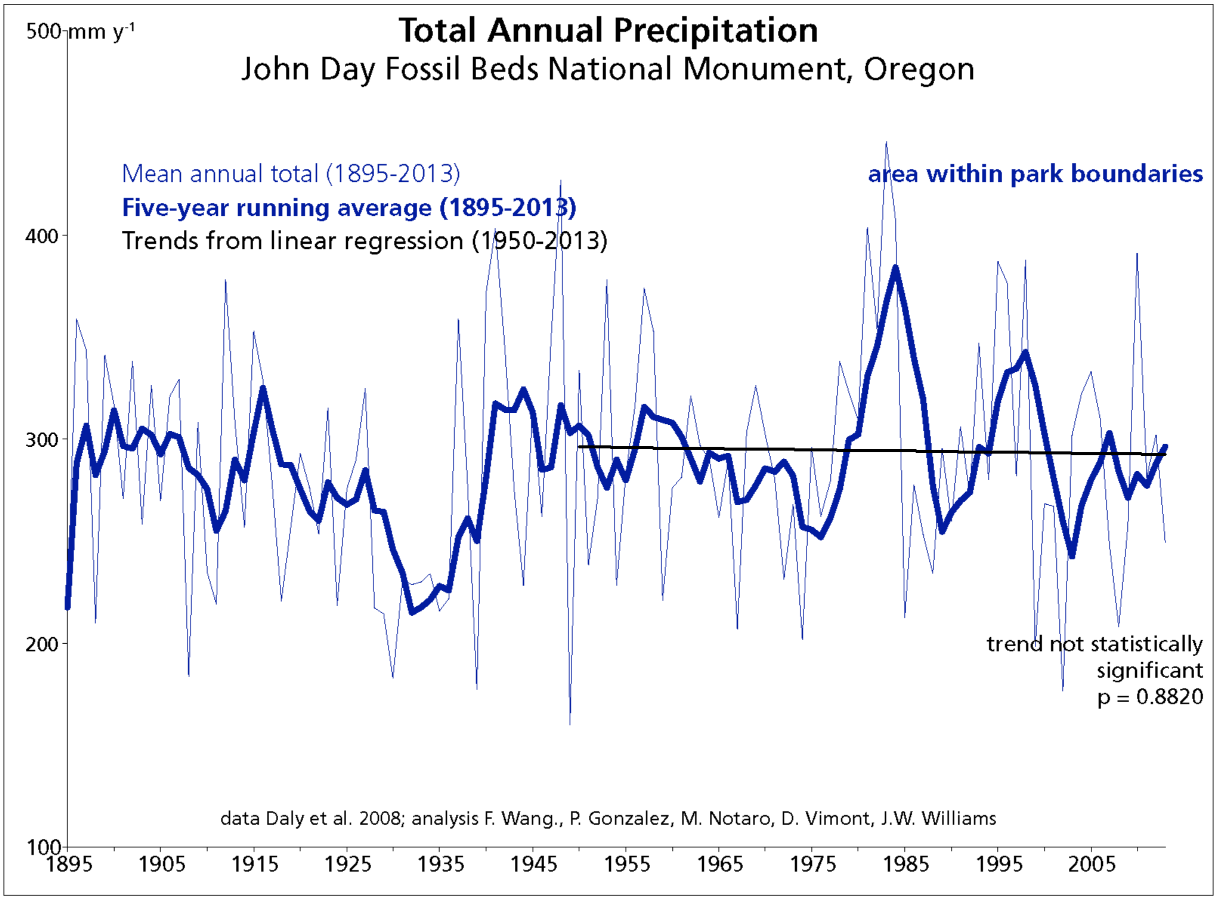
Figure 1.



Main conclusion: Temperature increased at a statistically significant rate in the park.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

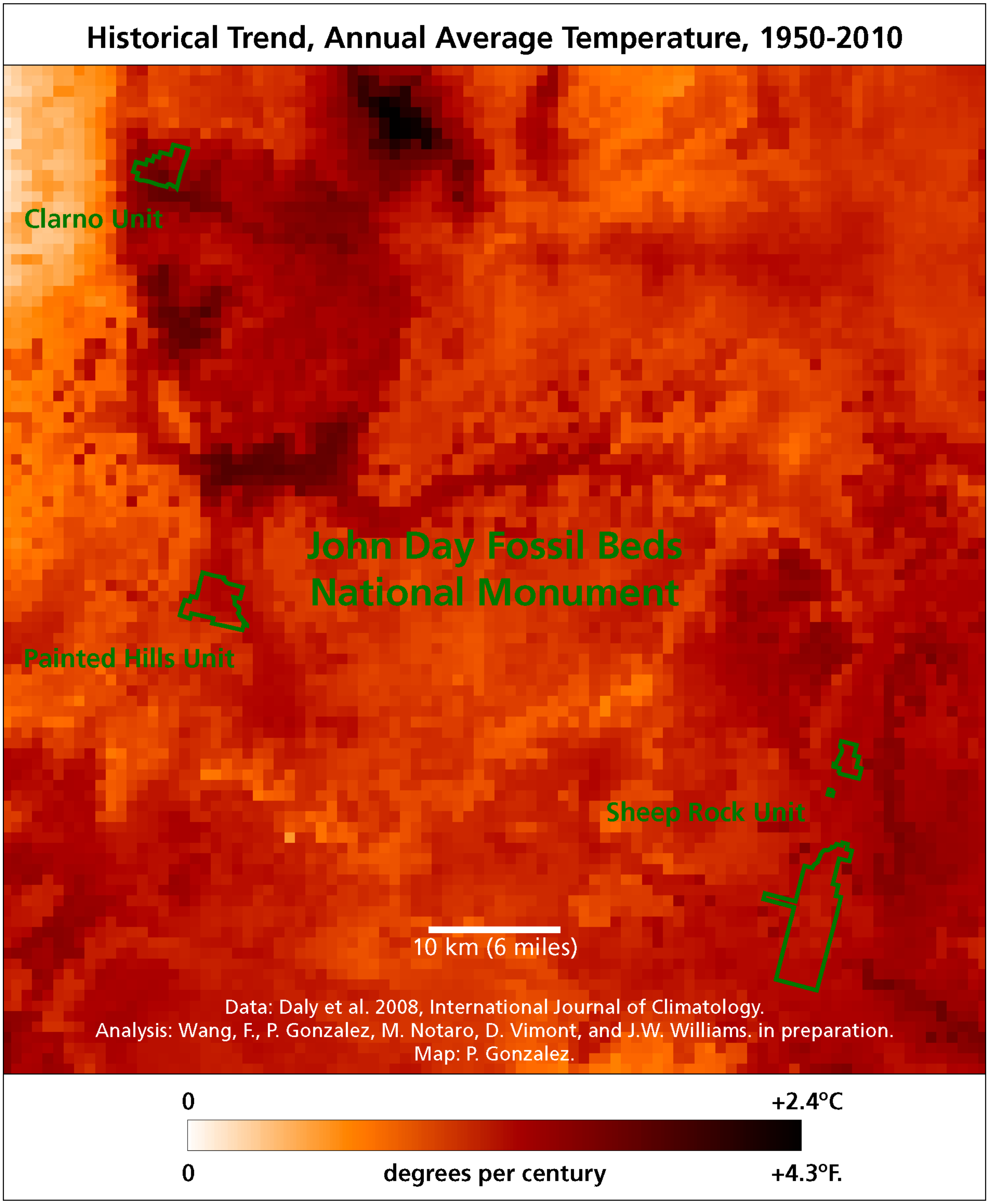
Figure 2.



Main conclusion: Precipitation decreased in the park, but the rate was not statistically significant.

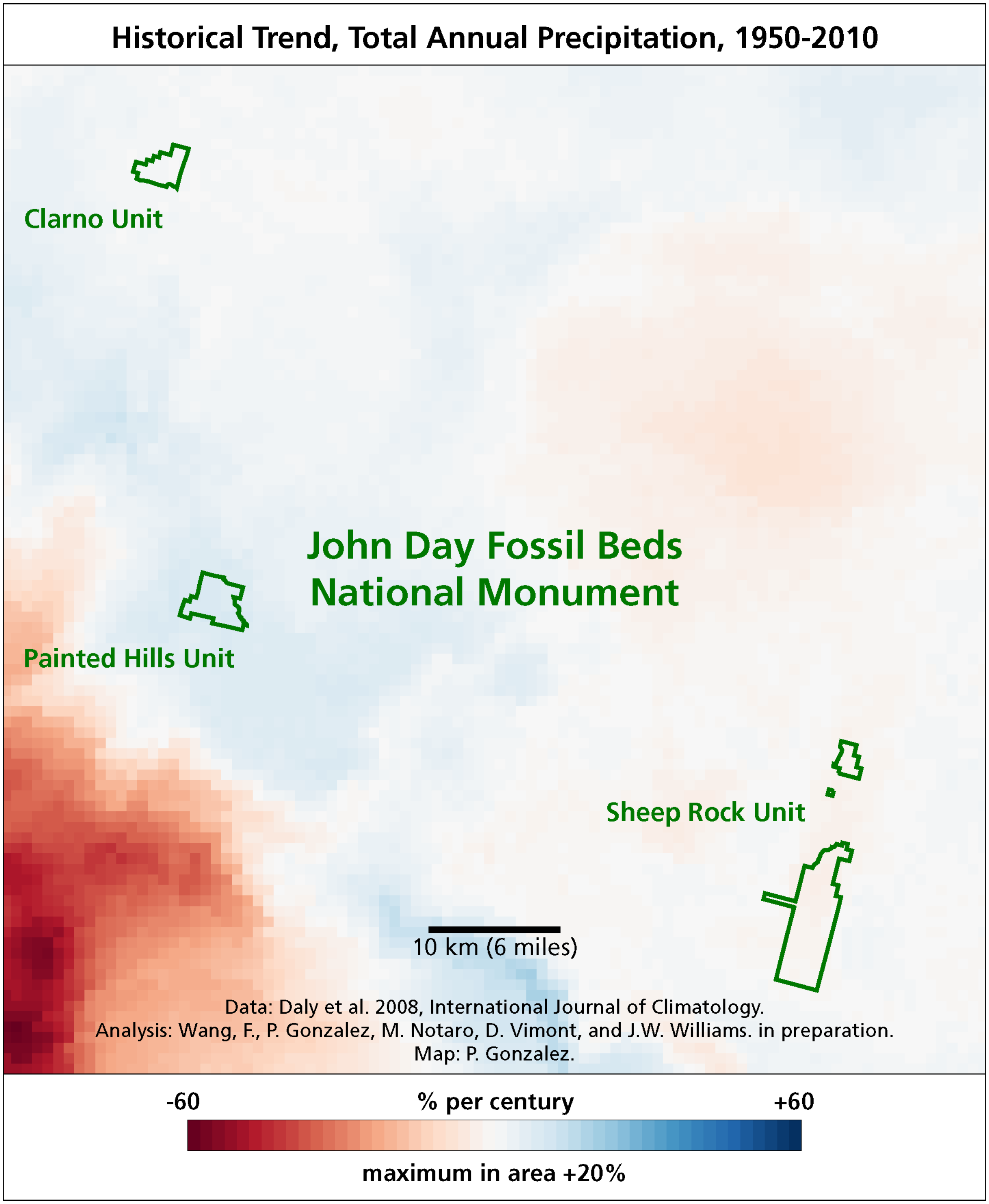
Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 3.



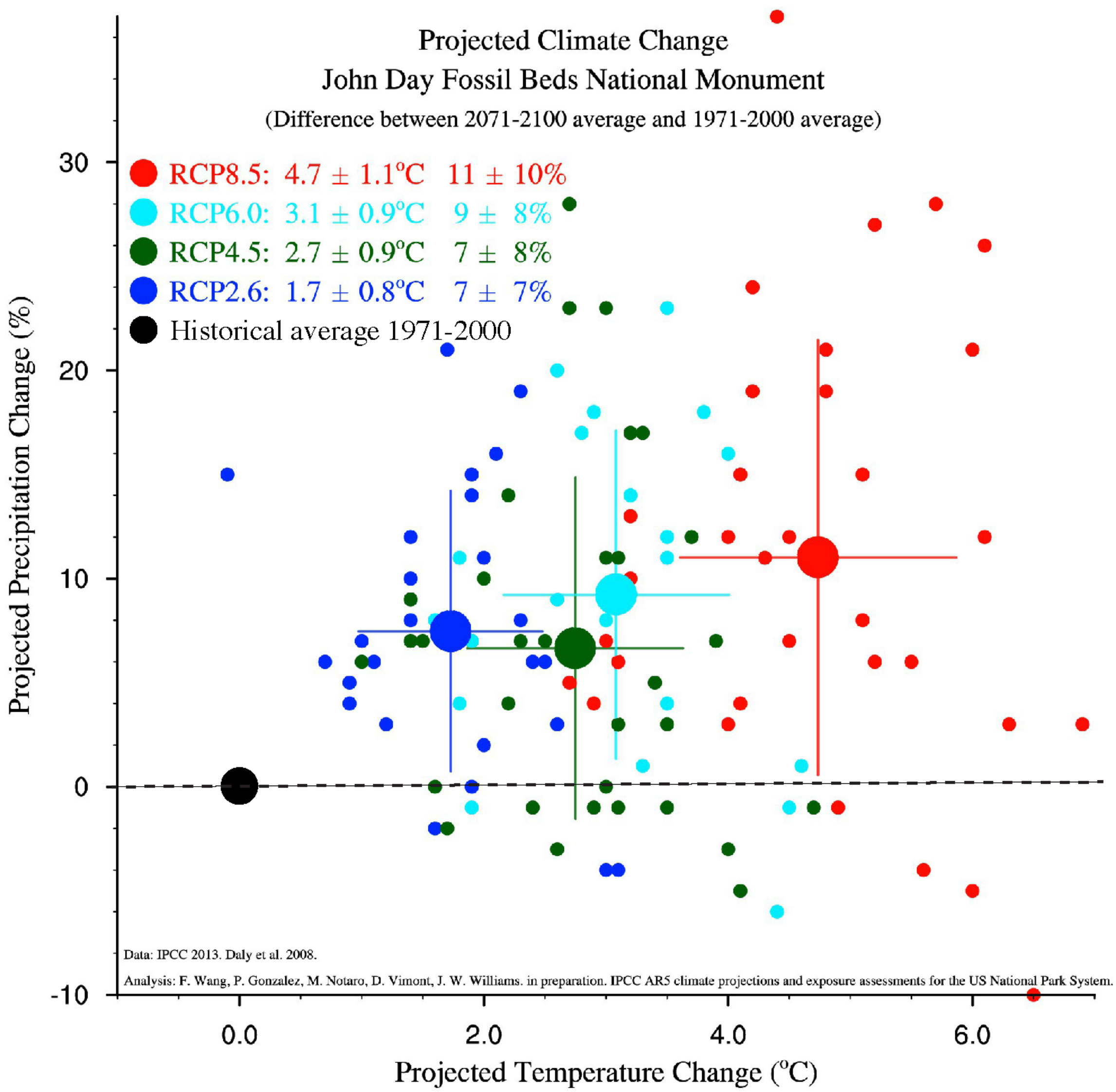
Main conclusion: Temperature increases have been greatest in the Clarno Unit.

Figure 4.



Main conclusion: Precipitation changes have been low in the park.

Figure 5.



Main conclusion: Models project temperature and precipitation increases in the park.

Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios and the historical baseline. The lines are the standard deviations of each average value.

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